

Modification of Soil Structure of Sand Tailings: 2. Effect of Silt, Sand and Clay Contents on Aggregate Development Using Organic Amendments

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ABSTRAK

Kesan bahan rangka (kelodak dan pasir sangat halus) dan lempung ke atas pembentukan agregat dan kestabilan agregat bagi tanah pasir (kandungan pasir, 99%) yang dirawat dengan bahan organik telah diselidiki. Dalam eksperimen ini, tanah pasir bekas lombong telah dicampurkan dengan slim (mengandungi 37% kelodak + pasir sangat halus dan 33% lempung) pada kadar yang berlainan. Kemudian campuran-campuran itu dirawat dengan efluen kilang kelapa sawit (POME) kering pada kadar 10.5 g bagi 1200 g campuran pasir-slim. Campuran-campuran itu diperam selama dua minggu dan selepas itu dikering-udarkan. Peratus pengagregatan ditentukan dengan ayakan kering dan kestabilan agregat dengan ayakan basah. Keputusan menunjukkan, penambahan kelodak + pasir sangat halus dan lempung meningkatkan pengagregatan dan kestabilan agregat tanah pasir. Nilai optimum lempung yang diperlukan untuk mendapatkan pengagregatan yang baik bagi banyaknya bahan organik yang ditambah ialah 25%. Ini memberikan peningkatan kestabilan agregat sebanyak tujuh kali ganda. Dengan menggunakan slim, yang mengandungi 33% lempung, nilai optimum lempung ini boleh dicapai daripada campuran 75% slim + 25% pasir lombong. Campuran ini mengandungi 32% bahan rangka.

ABSTRACT

The effect of skeletal materials (silt and very fine sand) and clay on aggregate formation and stabilization of organically amended sand tailings (99% sand) was investigated. In this experiment, sand tailings were mixed with different proportions of slime (slime contains 37% silt + very fine sand and 33% clay) and then treated with palm oil mill effluent (POME) cake at the rate of 10.5 g of POME cake per 1200 g of sand-slime mixture. The mixtures were incubated for 2 weeks and then air-dried. The extent of aggregation of the samples was determined by dry sieving, and the aggregate stability by wet sieving. The addition of silt + very fine sand and clay improved aggregation and aggregate stability of the sandy soils. The optimum amount of clay required to achieve a good aggregation and aggregate stability for the amount of organic matter added is 25%, where the increase in stability was seven-fold over the control. With slime, which contains 33% clay, this amount of clay can be achieved from a mixture of 75% slime + 25% sand tailings. This mixture contains 32% skeletal materials.

INTRODUCTION

Organic matter is the main binding agent in soil aggregate formation and stabilization (Tisdall and Oades 1982; Chaney and Swift 1984; Bartoli *et al.* 1988). Field experiments have shown that organic amendments such as sewage sludge im-

prove the structural stability of soils on which they are applied (Kladivko and Nelson 1979; Pagliai *et al.* 1981). While this is true for mineral soils, Lim *et al.* (1983) and Othman *et al.* (1990) have shown that the addition of organic amendments to sand tailings fail to give a positive

response on the aggregation and stability of these soils. Recently, Mokhtaruddin and Norhayati (1995) suggested that the lack of aggregation on sand tailings with the application of organic amendment is due to an insufficient amount of very fine sand and silt-size fractions and clay in the soils. According to Emerson (1959) the first two are important skeletal materials for aggregate formation. Mokhtaruddin and Norhayati (1995) concluded that the development of soil aggregation in sand tailings using organic amendments needs the introduction of sufficient amounts of these materials and clay.

The objectives of this paper are, first, to evaluate the effect of different amounts of silt, very fine sand and clay on aggregation and stability of sand tailings and, second, to determine the minimum amount of these materials need to obtain a substantial degree of aggregation and stability of these soils. The results will lead to a better understanding of the mechanism of aggregate development in these very marginal soils following organic matter application.

MATERIALS AND METHODS

Soil

Sand tailings (Table 1) have a high sand content. The silt and very fine sand content is 5.8% and clay is found in trace amounts.

The sand is acidic, has low carbon content and trace amounts of free iron oxides. The sand tailings were air-dried and sieved through a 2-mm screen.

Slime is the suspended fine fraction of the slurry pumped during tin-mining operations into a retention area for settlement. The content of silt, clay and very fine sand can be as high as 71% (Table 1). It can therefore be used to supply the fine materials required for promoting aggregation in the sandy portion of the tin tailings. Slime was obtained from the top layer of the slime retention area. It was air-dried and sieved through a 2-mm screen.

Palm Oil Mill Effluent (POME) for Organic Amendment

The type of POME used was decanter-dried raw POME cake. The nutrients and carbon contents of the cake are given in Table 2. The cake has a high content of N, K, Ca and carbon.

Experimentation

The sand tailings were mixed with various amounts of slime and then treated with the POME cake at the rate of 10.5 g POME cake per 1020 g of sand-slime mixture. The amount of slime added was calculated to give equivalent percentages of the clay fraction of 0 (control), 3, 7, 10, 15, 20 and

TABLE 1
Texture and chemical properties of sand tailings and slime

| Fraction | Size (mm) | Sand tailings | Slime |
|----------------------|------------|-----------------|-------|
| Course sand (%) | > 0.50 | 17.4 | 5.4 |
| Medium sand (%) | 0.25–0.50 | 35.1 | 9.3 |
| Fine sand (%) | 0.10–0.25 | 40.9 | 14.7 |
| Very fine sand (%) | 0.05–0.10 | 5.6 | 4.4 |
| Silt (%) | 0.002–0.05 | 0.2 | 32.7 |
| Clay (%) | < 0.002 | Tr ^a | 33.4 |
| Carbon (%) | | 0.15 | 1.66 |
| Free iron oxides (%) | | Tr ^a | 0.22 |
| pH | | 5.42 | 5.77 |

^aTr = Trace

TABLE 2
Chemical properties of palm oil mill effluent cake

| Element | N | P | K | Ca | Mg | Fe | C |
|-------------|------|------|------|------|------|------|------|
| Content (%) | 1.14 | 0.17 | 0.99 | 1.99 | 0.24 | 0.14 | 14.4 |

25%. The total weight of each mixture was made up to 1200 g. The mixtures were thoroughly mixed and sprayed with 0.1% iron solution (ferrous sulphate) until field capacity, the moisture content at which maximum aggregate formation is attained in many soils. Iron solution at 0.1% concentration was found to enhance the aggregate stabilization in sand soils (Mokhtaruddin and Norhayati 1995). The field capacity (moisture content at 100 cm water tension) was determined using the pressure plate apparatus. Samples were placed in plastic bags and incubated for one week at ambient temperature. After incubation they were air-dried. The extent of aggregation was evaluated by dry sieving. A 100-g air-dried sample was placed on a nest of sieves with 2.0, 1.0, 0.5 and 0.3 mm openings. The nest of sieves was shaken manually 10 times with a circular motion. Aggregates remaining on each sieve were weighed. The extent of aggregation was expressed as the proportion of air-dried aggregates > 2 mm (% aggregation > 2 mm). The stability of soil aggregates was expressed as a percentage of water-stable aggregates > 0.5 mm (% WSA > 0.5 mm) (Bryan 1968). Percentage WSA > 0.5 mm was determined by the wet sieving technique of Yoder (1936). A 100-g air-dried sample (< 2 mm) was placed on a 0.5 mm screen. The screen was shaken up and down mechanically in water at a frequency of 40 oscillations per minute for 30 minutes. The height of oscillation was 4 cm. The aggregates remaining on the sieve were dried and weighed. The % WSA > 0.5 mm

was calculated as the proportion of water-stable aggregates > 0.5 mm over the whole sample. To determine the particle size distribution, the samples were analysed mechanically by the pipette method using calgon as the dispersing agent (Day 1965). Each treatment was repeated on three samples for each mixture.

RESULTS AND DISCUSSION

Extent of Aggregation

In its natural state, sand tailings have a single grain structure. The poor development of aggregation in the sandy soils was thought to be due to the very low content of very fine sand and silt fractions, absence of clay and low content of organic matter (Mokhtaruddin and Norhayati 1995). Emerson (1959) suggested that the combination of these materials formed stable soil aggregates. The addition of these materials to sandy soils should therefore improve soil aggregation substantially. Fig. 1 shows that

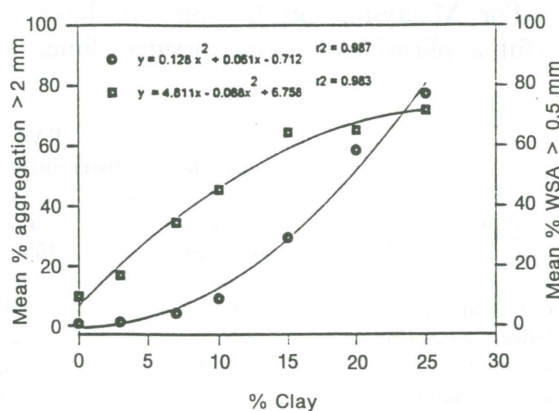


Fig 1. Regression curves of % aggregation > 2 mm [○] and % WSA > 0.5 mm [◻] against % Clay

the mean % aggregation > 2 mm increased with increase in clay content. The increase is significant compared with the control. The greatest increase occurred when the clay content was above 10%. At 10% clay, the increase was 13-fold over the control and at 15% clay, the increase was 40-fold. An addition of 20% clay caused an 82-fold increase in aggregation over the control, and by extrapolation the addition of 30% clay gave a 164-fold increase in aggregation. However, aggregate stability is more important in aggregate formation.

Aggregate Stability

Fig. 1 shows that not only the aggregation status of sand tailings was improved; the addition of clay also produced water-stable aggregates. All levels of clay caused a significant increase in % WSA > 0.5 mm ($P < 0.05$). However, the rate of increase in stability decreased with increase in clay content. The results also suggest that there is an optimum amount of clay for aggregate formation and stabilization in sand tailings. This optimum amount was found to be 25%, where the increase in stability was 7-fold over the control. The 25% clay is obtained from a mixture of 75% slime + 25% sand tailings (Table 3). The amount of very fine sand + silt in this mixture is 32%.

For Malaysia, this finding can have useful applications because besides slime,

“fly ash” (solid waste from coal burned for energy production), which contains 96% silt + very fine sand particles, can be used as a source of the skeletal materials.

As mentioned above, silt + very fine sand fractions are important skeletal materials for aggregate formation. It is well known that clay particles are cementing material, which bind the skeletal materials together into stable aggregates (Peterson 1946; Kemper and Koch 1966; Dixon 1991). The presence of an organic colloid results in stronger binding by forming strong clay-organic matter complexes (Cailer and Visser 1988; Greenland 1965; Theng 1979). Emerson (1959) suggested another mechanism by which clay-organic matter interaction influences the stability of aggregates. Organic matter is bonded to the exterior surfaces of the clay domains leaving the clay still free to shrink and swell. When the clay swells, the stresses are transmitted via the organic matter bonds and the bridging between quartz (skeletal) particles remains intact and slaking is thus prevented.

Greenland (1971) has discussed the various ways in which organic ions are adsorbed by clay surfaces through the influence of aluminium and iron hydroxides on the clay surfaces. Firstly, the organic ions are adsorbed to the positive sites on the aluminium and iron hydroxides

TABLE 3
Particle size distribution of clay-sand mixtures

| Fraction | 10% clay ^a (30% slime) | 15% clay ^a (45% slime) | 20% clay ^a (60% slime) | 25% clay (75% slime) |
|--------------------|--------------------------------------|--------------------------------------|--------------------------------------|-------------------------|
| Course sand (%) | 11.3 | 10.1 | 8.8 | 7.5 |
| Medium sand (%) | 24.8 | 21.5 | 18.2 | 14.9 |
| Fine sand (%) | 32.0 | 28.2 | 24.6 | 20.9 |
| Very fine sand (%) | 6.7 | 6.3 | 5.8 | 5.3 |
| Silt (%) | 15.0 | 18.8 | 22.5 | 26.3 |
| Clay (%) | 10.0 | 15.0 | 20.0 | 25.0 |

^a Figure in brackets is % of slime which contains the respective amount of clay

by simple coulombic attraction. Secondly, organic ions can be bonded to aluminium and iron hydroxides through 'ligand exchange' reactions or specific adsorption. Another way by which organic substances can be bonded to clay surfaces is through precipitation by iron and aluminium hydroxides followed by dehydration. Thus it is expected that the role of clay and organic matter in aggregate stabilization will depend on the amount of clay and organic matter present in the sample. Either one can be the limiting factor. This could explain why in this experiment, further addition of clay (> 25%) with the same amount of organic matter did not produce a further increase in aggregate stability.

CONCLUSION

Addition of clay and skeletal materials (silt and very fine sand) to organically amended sandy soils (> 99% sand) not only significantly improved the aggregation status but also the aggregate stability of the soils. The optimum amount of clay required to achieve a good aggregation and aggregate stability is 25%. If slime, which contains 33% clay, is used to supply the required clay, this condition can be achieved by preparing a mixture of 75% slime and 25% sand. This mixture will contain 32% skeletal materials. The addition of these amounts of clay and skeletal materials, and POME cake at the rate of 10.5 g per 1200 g mixture of these materials resulted in a 7-fold increase in aggregate stability.

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